

Test measurements of thoron concentration using two ionization chambers AlphaGUARD vs. radon monitor RAD7

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Abstract. The experiment aiming at testing the possibility of using AlphaGUARD monitors based on an ionization chamber for thoron measurements is presented. A single AlphaGUARD monitor working in the flow mode was applied to measure thoron concentration in the radon-free atmosphere. The sensitivity (correction factors) of the monitor to thoron was estimated by comparison with a RAD7 portable detector (DurrIDGE Company), based on spectrometric analysis, in the thoron, radon-free atmosphere in a calibration chamber. This depends on the applied flow rate and changes from 8% for the flow rate of 0.3 dm³/min to 36% for 1 dm³/min. It was also revealed that the sensitivity of the monitor to thoron in the diffusion mode is equal to ca. 5% and may be neglected. The method involving two AlphaGUARD monitors working in two different modes (diffusion and flow) at the same time may be used to evaluate radon and thoron concentration in the natural environmental conditions where usually both isotopes appear together. In this method thoron concentration is estimated as the difference of results obtained from two AlphaGUARD monitors multiplied by the correction factor corresponding to the applied flow rate. The devices based on spectrometric analysis, e.g. RAD7 seem to be a better tool for thoron measurements in the environmental conditions.

Key words: radon • thoron • thoron concentration • ionization chamber

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Introduction

Thoron ²²⁰Rn is one of four naturally occurring radon isotopes. It has a half-life $T_{1/2}$ equal to 55 s. Radon isotopes are chemically inert radioactive gases that occur in the environment as a result of the decay of radioactive elements in soil and minerals. While radon ²²²Rn results from the decay chain of uranium ²³⁸U, thoron ²²⁰Rn results from the decay of thorium ²³²Th. Both uranium and thorium are commonly found in soil and minerals. The radioactive gases radon and thoron that are produced there can diffuse out of the material and travel at long distances before they decay. Both radon and thoron decay into their progenies: polonium, lead and bismuth before finally reaching stable forms of lead.

Thoron and radon and their respective progenies differ very significantly in their half-lives and in the energies of their radiations. While radon ²²²Rn has a half-life of 3.82 d, thoron ²²⁰Rn has a half-life of only 55 s. Since thoron is so short-lived, it cannot travel as far from its source as radon can before it decays. It is commonly observed that compared to radon, a much smaller fraction of thoron gas in soil ever reaches the interior of a building. However, in some cases thoron can still be a hazard since its progeny ²¹²Pb with a half-life of 10.6 h can accumulate to significant levels in breathable air.

The presence of thoron was often neglected because it was considered that the quantity of thoron in the en-

vironment was much less than that of radon. However, recent studies have shown that high thoron concentrations were found in some regions, and the exposure to ^{220}Rn and its progenies can equal or even several times exceed that of ^{222}Rn and its progenies [1, 2, 4, 5, 10].

Because of its characteristics, thoron gas is difficult for accurate measurement. The presence of radon gas (often found together with thoron) can interfere with a measurement. The short half-life of thoron gas makes a sampling method the critical issue. Thoron concentration can vary greatly through atmosphere, depending on the speed and direction of air flow as well as turbulence. The position of the sample collecting can strongly affect the results [7, 8].

In many instruments, such as those built as ionization chamber, radon and thoron interfere with each other. It is difficult to measure accurately one isotope in the presence of the other.

The Laboratory of Radiometric Expertise, IFJ PAN, Kraków, Poland in collaboration with the University of Silesia, Katowice, Poland tried to investigate the sensitivity of the AlphaGUARD to thoron. Both the diffusion and flow modes were taken into consideration. The RAD7 monitor from DurrIDGE Company, USA was used as a reference monitor for radon and thoron concentration measurements. The aim of this experiment was to test the possibility of using the ionization chamber AlphaGUARD for environmental thoron measurements.

The additional aim was to check if and to what extent the presence of thoron in the environment may influence the results of radon measurements.

Method

In this Laboratory the ionization chamber AlphaGUARD PQ 2000PRO (Genitron GmbH, Germany) is used for environmental radon measurements. The AlphaGUARD is a portable, real-time ionization chamber. At present, there are about 1000 units in operation in the world. The AlphaGUARD is a very popular and recognized as reference device for radon measurements because of its advantages. It can measure radon in air, soil, water and building materials, and it can simultaneously monitor air temperature (in the range from -10°C to $+50^{\circ}\text{C}$), air pressure (from 700 mbar to 1100 mbar) and air humidity (from 0% to 99%). It can operate on internal battery for 10 days in two modes: diffusion mode (with 10 min and 60 min measuring cycles) and flow mode (1 min or 10 min measuring cycles). The important feature of the AlphaGUARD is its linear response from 2 Bq/m^3 to 2 MBq/m^3 of ^{222}Rn concentration [9]. A disadvantage of this device is that it detects alpha emitters without energy discrimination. For that reason, it is worth examining how much thoron presence can increase the result of radon measurement. It was found by Ishikawa [3] that the AlphaGUARD working in the diffusion mode has a relative sensitivity to thoron on the level of 10%. The flow mode of the AlphaGUARD was not investigated by the author.

The measurements were held in the Laboratory of Radiometric Expertise in Kraków in collaboration with the University of Silesia in Katowice. The mea-

surements were performed using a radon calibration chamber of 600 dm^3 volume, which could be tightly closed with a cover. The calibration facility consisted also of a control panel, valves and pipes (which enabled, e.g., to ventilate it before and after the exposure and to connect additional devices). Thoron was generated from a thorium ^{228}Th PYLON source (the activity of the source: $295 \pm 24\text{ kBq}$, date certified: 4th January 1993). A fan was used to ensure homogeneous thoron concentration in the chamber. By adjusting the flow rate of a pump connected to thoron source different thoron concentrations were obtained.

Three different thoron concentrations were equal to 9300 Bq/m^3 , 7400 Bq/m^3 and 5500 Bq/m^3 depending on the flow rate of the pump ($1\text{ dm}^3/\text{min}$, $0.5\text{ dm}^3/\text{min}$ and $0.3\text{ dm}^3/\text{min}$, respectively). The measurement scheme is presented in Fig. 1. Two AlphaGUARD monitors were placed in the radon chamber. One of them operated in the diffusion mode, the other one in the flow mode with different flow rates ($0.3\text{ dm}^3/\text{min}$, $0.5\text{ dm}^3/\text{min}$ and $1\text{ dm}^3/\text{min}$). In order to continuously monitor thoron concentration in the chamber the professional radon monitor RAD7 (working in the flow mode with a flow rate of $1\text{ dm}^3/\text{min}$) was used. It was placed outside the chamber and connected to it with plastic pipes. The length of the pipes was standardized by the producer. The operation principle of the RAD7 device is based on the spectral analysis of alpha-emitters. High-precision alpha-energy spectrum obtained from the solid-state ion-implanted planar silicon detector identifies isotopes from radon and thoron decay chains.

The RAD7's internal sample cell is a 0.7 dm^3 conducting hemisphere with a 2200 V potential relative to the detector that is placed at the center of the hemisphere. The detector operates in external relative humidity ranging from 0% to 95% and internal humidities of 0% to 10% with the low detection threshold of 4 Bq/m^3 and an upper linear detection limit of 400 kBq/m^3 . The detector was calibrated with an accuracy of 5%. The spectra are in 200 channels and the RAD7 groups them into eight windows of different energy ranges. *A*, *B*, *C*, and *D* are the major windows and *E*, *F*, *G*, and *H* are the

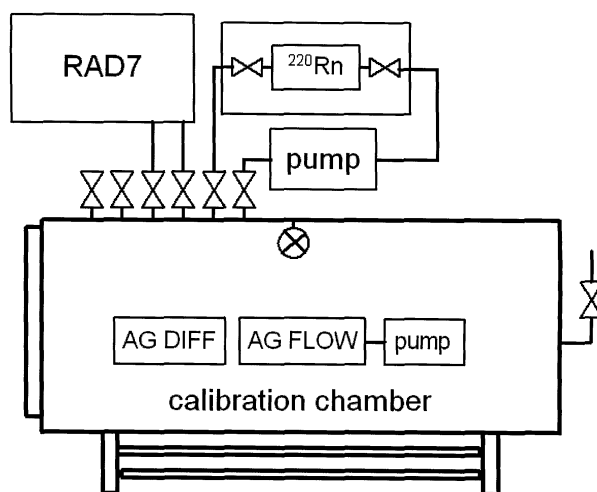


Fig. 1. Measurement scheme: ^{220}Rn – thoron source; AG DIFF – the AlphaGUARD monitor working in “diffusion mode”; AG FLOW – the AlphaGUARD monitor working in “flow mode”.

Table 1. Thoron concentration measured by RAD7 and AlphaGUARD monitors with the respective correction factors

	Thoron concentration (Bq/m ³)				
	RAD7	AlphaGUARD			Correction factor
		Minimum value	Maximum value	Average	
AG DIFF	9300 ± 250	323	632	433 ± 86	21 ± 4
	7400 ± 500	277	456	354 ± 49	21 ± 3
	5500 ± 400	194	382	268 ± 52	21 ± 4
AG FLOW 0.3 dm ³ /min	9300 ± 250	794	1097	933 ± 111	10 ± 1
	7400 ± 500	613	833	727 ± 89	10 ± 1
	5500 ± 400	294	505	433 ± 95	13 ± 3
AG FLOW 0.5 dm ³ /min	9300 ± 250	1089	1803	1472 ± 296	6 ± 1
	7400 ± 500	997	1442	1104 ± 244	7 ± 2
	5500 ± 400	668	860	740 ± 83	7 ± 1
AG FLOW 1.0 dm ³ /min	9300 ± 250	2736	4653	3235 ± 803	3 ± 1
	7400 ± 500	2165	2771	2684 ± 331	3 ± 1
	5500 ± 400	1058	1729	1476 ± 275	4 ± 1

diagnostic windows. Windows *A* and *B* represent “new” ²²²Rn and ²²⁰Rn, while windows *C* and *D* represent “old” ²²²Rn and ²²⁰Rn, respectively. The RAD7 separates ²²²Rn and ²²⁰Rn signals by their progenies’ unique α -particle energies with little cross interference which means that it counts two isotopes at the same time [6]. The RAD7 responds virtually instantly to the presence of thoron. Its time constant for the response to thoron is less than 1 min. As it was mentioned above, the RAD7 calculates thoron concentration on the basis of the count rate in the alpha line of ²¹⁶Po (energy 6.78 MeV), the first decay product of thoron gas. Thoron calibration precision is $\pm 25\%$. The measurements were done using the “thoron protocol” with a 5 or 30 min repeating cycle [6]. For each thoron concentration the experiment was repeated about 10 times.

Results

The results of the AlphaGUARD ionization chambers working in the diffusion and flow mode are shown in Table 1. In the flow mode, typical for AlphaPUMP, three flow rates were applied (0.3 dm³/min, 0.5 dm³/min, 1.0 dm³/min). For each case, the correction factor was calculated as a quotient of the thoron concentration measured by the RAD7 and the same concentration measured by the AlphaGUARD. The AlphaGUARD monitors always showed lower values than the RAD7, however it may be stated that they were sensitive to thoron. In Table 2, “the AlphaGUARD sensitivity” to thoron is presented. The parameter was calculated as a percentage ratio of thoron concentration measured by the AlphaGUARD to that measured by the RAD7.

AlphaGUARD, diffusion mode

In the diffusion mode the correction factor is equal to 21 ± 4 , independently of thoron concentration. The sensitivity to thoron is at the level of 5%. The glass fiber filter at the entrance to the ionization chamber seems to be a quite effective diffusion barrier for thoron gas.

AlphaGUARD, flow mode

In the flow mode of the AlphaGUARD thoron is better detected by the device because of pumping, which forces a faster inflow of this gas into the ionization chamber. As a result, the loss of thoron due to the decay is decreased. Thus, the amount of measured thoron increases with increasing flow rate. The correction factors are shown in Table 1. It can be seen that the correction factor depends on the flow rate and it decreases with increasing flow rate. According to that, also “the AlphaGUARD sensitivity” to thoron (defined in the first paragraph) changes with flow mode: from 8% (0.3 dm³/min) to 36% (1 dm³/min) (Table 2).

Conclusions

The professional radon monitor AlphaGUARD is commonly used for environmental radon measurements, i.e. radon concentration in air, soil and water. One of the aims of this investigation was to test if this monitor can also be applied for measurements of environmental thoron, having in mind that it detects alpha emitters without energy discrimination. The additional goal was

Table 2. “The AlphaGUARD sensitivity” to thoron for various flow rates

Thoron concentration (Bq/m ³)	AlphaGUARD sensitivity (%)			
	Average value (min ÷ max)			
	AG DIFF	AG FLOW 0.3 dm ³ /min	AG FLOW 0.5 dm ³ /min	AG FLOW 1.0 dm ³ /min
9300	5 (3 ÷ 7)	10 (9 ÷ 12)	16 (12 ÷ 19)	35 (29 ÷ 50)
7400	5 (4 ÷ 6)	10 (8 ÷ 11)	15 (13 ÷ 19)	36 (29 ÷ 37)
5500	5 (4 ÷ 7)	8 (5 ÷ 9)	13 (12 ÷ 16)	27 (19 ÷ 31)

to check if and in what extent thoron presence in the environment may influence the result of the measurement of radon.

The performed laboratory experiment indicated that the AlphaGUARD monitor, despite its main destination – radon concentration, is sensitive to thoron when it works in the flow mode.

The most typical active method to check radon level in air in dwellings and in atmospheric air is to perform measurements with the AlphaGUARD working in the diffusion mode. As it was shown, in this case its sensitivity to thoron is around 5%. Thus, the influence of thoron presence on radon determination can be neglected.

The situation is much more complicated for measurements of radon in soil gas performed using the flow mode, when “the AlphaGUARD sensitivity” to thoron is more significant (Table 2). In this case one has to be aware of the influence of thoron presence on the obtained results of radon measurement. The possible way to determine radon correctly is to apply an appropriately long pipe for connecting a soil probe with the ionization chamber of the AlphaGUARD, which enables thoron to decay before reaching the monitor.

However, the overall analysis showed that if thoron concentration in soil gas is the point of interest the devices based on spectrometric analysis (e.g. RAD7) seem to be the best tool for thoron measurements.

The presented test measurements indicated that a single AlphaGUARD monitor is not a suitable instrument for the determination of thoron concentration in natural environmental conditions.

However, there is a possibility to determine thoron concentration in air using two AlphaGUARD monitors. One of them has to work in the diffusion mode (assuming that it registers only radon concentration) and the other one has to work in the flow mode with the flow rate of 1 dm³/min (the highest flow rate delivered by the

AlphaGUARD pump). The thoron concentration can be then evaluated using the following procedure:

1. Subtract the result obtained by the AlphaGUARD working in the diffusion mode from the result from the AlphaGUARD working in the flow mode.
2. Multiply the obtained value by the correction factor, adequate to the applied flow rate.

References

1. Doi D, Kobayashi S, Fujimoto K (1992) A passive measurement technique for characterization of high-risk houses in Japan due to enhanced levels of indoor radon and thoron concentrations. *Radiat Prot Dosim* 45:425–430
2. Giargoni E, Honing A, Rottger A (2003) Development of a calibration facility for measurements of the thoron activity concentration. *Nucl Instrum Methods Phys Res A* 506:166–172
3. Ishikawa T (2004) Effects of thoron on a radon detector of pulse-ionisation chamber type. *Radiat Prot Dosim* 4:327–330
4. Mjones L, Falk R, Mellander H, Nyblom L (1992) Measurements of thoron and thoron progeny indoors in Sweden. *Radiat Prot Dosim* 45:249–352
5. Nuccitelli C, Bochicchio F (1998) The thoron issue: monitoring activities, measuring techniques and dose conversion factors. *Radiat Prot Dosim* 78:59–64
6. Rad7 User Manual (2000) DURREIDGE Co, USA
7. Steinhausler F, Kotrappa P (1996) Radon. In: Proc on the IRPA9 Int Congress on Radiation Protection, Radon Refresher Course, 14–19 April 1996, Vienna, Austria, p R-01
8. Tokonami S (2005) Summary of dosimetry (radon and thoron) studies. *Int Congress Series* 1276:151–154
9. User Manual Portable Radon Monitor AlphaGUARD (1998) Genitron Instruments GmbH, Germany
10. Zhuo W, Iida T, Yang X (2000) Environmental radon and thoron progeny concentrations in Fujian province of China. *Radiat Prot Dosim* 87:137–140